(NASA-CR-170953) COMMERCIALIZATION OF OPPORTUNITIES FOR MATERIALS PROCESSING IN LOW GRAVITY Final Report (Brown (W. S.), Inc.) 35 p HC A03/MF A01 CSCL 22A

N84-15165

Unclas
G3/12 43329

FINAL REPORT
NASA CONTRACT NAS8-34901

COMMERCIALIZATION OF OPPORTUNITIES FOR MATERIALS PROCESSING IN LOW GRAVITY

Submitted By

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Investigators

Dr. Wayne S. Brown
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Prepared For

National Aeronautics and Space Admistration
George C. Marshall Space Flight Center
Alabama 35812

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Table of Contents

Introduction

Utilization of the low gravity environment available in space for processing materials has been a subject of considerable interest since the early days of the space program. NASA has sponsored ground-based research, short duration low gravity experiments in aircraft and rockets, as well as longer term experiments in orbiting vehicles, to develop an understanding of the physical phenomena associated with materials behavior in low gravity. An active research program is currently underway covering a broad range of topics. In addition to the scientists working in NASA laboratories, strong ties have been established with a number of well-qualified scientists from academic and industrial laboratories who participate in the program.

Through numerous presentations NASA has invited industrial organizations to participate in the effort to commercialize materials processing in space (MPS). Innovative working agreement arrangements have been established by NASA which permit private industry to utilize NASA facilities, including the space shuttle, and to interact extensively with NASA personnel. However, only a few American companies have become involved in MPS programs. If America is to fully capitalize commercially on its investment and technically superior position in space, ways must be found to encourage greater industry involvement in MPS.

This report presents the results of a study conducted to determine the status of MPS from a commercialization viewpoint and to find ways to enhance commercial use of the low gravity environment. Data for the study was gathered from extensive interviews with NASA scientists and administrators, academic and industry researchers, and managers of industrial firms either currently involved in MPS or anticipating future involvement. This provided the information necessary to assess the status of commercial MPS and to analyze alternatives for encouragement of private industry involvement in MPS programs.

Background

A team of NASA personnel from the Marshall Space Flight Center has been involved in efforts to encourage U.S. corporations to become involved in MPS research and development programs for several years. This team has made presentations and conducted interviews with numerous American corporations. Discussions between members of the NASA team and the investigators led to this contractual effort. The investigators have had extensive personal experience with commercializing technical innovation in both large and small firms, as well as experience in the aerospace industry. Dr. Brown is now president of the Utah Innovation Center and professor of mechanical engineering at the University of Utah. He has been instrumental in starting several successful high technology companies. Mr. Nixon is a private consultant with extensive experience commercializing technology in the nuclear and aerospace industries. Their combined experience provided a viewpoint quite different to that of the NASA team. It was concluded that this viewpoint could be useful in assisting the NASA team in their ongoing efforts to encourage private investment into MPS technology.

Objectives

The objectives of this study were to review ongoing NASA MPS research for its commercial potential and to search out logical combinations of talent, interest and resources needed to foster commercialization of selected promising research or ideas. Three specific tasks were established to achieve these objectives. The tasks are summarized in Figure 1.

CONTRACT TASKS

A. ASSESSMENT OF COMMERCIAL POTENTIAL

- REVIEW RESEARCH & FACILITIES
- INTERVIEW P.I.'s
- IDENTIFY POTENTIAL COMMERCIAL AREAS
- FOCUS ON LIKELY COMPANIES

B. DATA ANALYSIS

- DETERMINE LOGICAL BUSINESS RELATIONSHIPS
- EVALUATE TALENTS, INTEREST AND RESOURCES OF P.I.'s
- REVIEW INCENTIVES AND DISINCENTIVES
- RECOMMEND INFRASTRUCTURE AND INTERACTION SCENARIOS

C. BUSINESS RELATIONSHIPS

- ATTEMPTS TO BRING TOGETHER APPROPRIATE ENTITIES LEADING TO PRIVATE INVESTMENTS
- IDENTIFY KEY FACTORS INFLUENCING PRIVATE INVOLVEMENT

FIGURE 1

TASK A: ASSESSMENT OF COMMERCIAL POTENTIAL

The primary means of reviewing the current NASA MPS program was reading documents supplied by NASA and conducting discussions with members of the NASA technical community. Extensive interviews were conducted with a number of individuals involved in MPS programs or having an interest in MPS. Beginning at the Marshall Space Flight Center the investigators had an opportunity to meet with NASA managers and scientists conducting research related to the MPS program. Considerable literature was made available which provided an excellent overview of the NASA MPS program. A tour of the extensive research laboratories and drop tubes at MSFC provided an overview of some of the facilities available to develop MPS technology on the earth. The space shuttle mockup was observed as well as some experimental flight hardware to gain an understanding of the facilities available for conducting materials processing experiments in the actual space environment.

After reviewing a large number of NASA-funded research programs, it was concluded that interviews should be limited to those projects which appeared to have the greatest possibility of leading to commercialization. With the assistance of NASA managers, a representative group of individuals was selected from the NASA-funded program which included research personnel from NASA laboratories as well as from universities and industry. In addition, a list of companies and private consultants actively involved in NASA projects was developed. Some of these companies had signed NASA working agreements to participate in MPS programs.

The interviews were normally held at the interviewers' site. In most cases both of the investigators were present for the interview, however, in a few cases the interviews were limited to telephone conversations. The investigators also attended MPS workshops, information meetings and Science Working Group meetings. Appendix 1 lists the names and organizations of individuals interviewed as part of this investigation. Figure 2 summarizes the research review activities and Figure 3 illustrates the geographical distribution of the interviews.

The interviews were extremely informative. They enabled the investigators to gain an understanding of the complexities of the technical problems and to assess the potential for commercialization. It was also possible to determine some of the problems associated with working with NASA facilities and the attendant extensive interface problem. Figure 4 summarizes impressions gained from the interviews concerning MPS. Figure 5 illustrates the variety of viewpoints which exist among NASA-funded P.I.'s.

The interviews identified several potential commercial areas which are summarized in Figure 6.

REVIEW RESEARCH

VISITED RESEARCH FACILITIES

CONTACTED OVER 60 PERSONS (40% OF P.I.'s)

- NASA SCIENTISTS, ACADEMIC P.I.'s, INDUSTRY P.I.'s

ATTENDED TWO WORKING GROUP MEETINGS

REVIEWED REPORTS

VISITED COMMERCIAL ENDEAVORS

- SERVICE RELATED: GTI, BALL BROS.
- PRODUCT RELATED: MDAC, MRA, ROCKWELL

GOVERNMENT AGENCIES: NASA, DOE

FIGURE 2

Location of Principle Investigators and Companies Visited

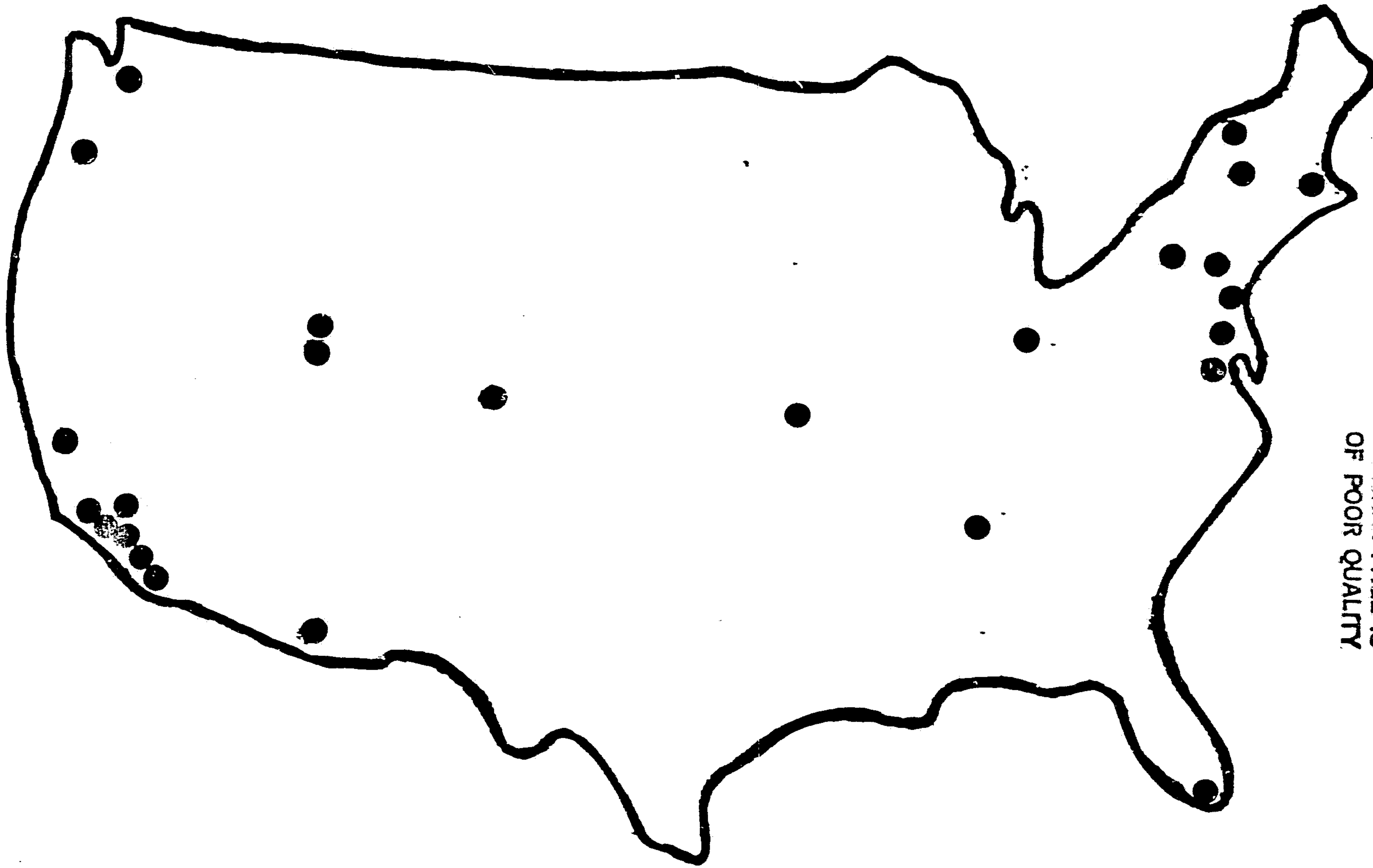

FIGURE 3

IMPRESSIONS GAINED FROM INTERVIEWS

MPS IS EXPENSIVE

LONG TERM INVESTMENT

UNCERTAIN PAYOUT

SPACE HARDWARE FOR MPS RESEARCH

- EXPENSIVE
- COMPLICATED (NASA INTERFACE)
- NOT AVAILABLE

FLIGHT SCHEDULING

- COMPLEX
- UNCERTAIN

FIGURE 4

VARIETY OF P.I.'S VIEWS

NEED AN ADEQUATE BASE OF SCIENTIFIC KNOWLEDGE BEFORE PROCEEDING WITH MPS APPLICATIONS

RESEARCH IN SPACE WILL LEAD TO BETTER GROUND BASED PROCESSING

SPACE CAN BE USED TO PRODUCE ULTIMATE MODELS OF MATERIALS. THEN GROUND BASED DEVELOPMENT CAN BE USED TO SOLVE CRITICAL PROBLEMS

SUPERIOR HIGH VALUE, LOW VOLUME MATERIALS CAN NOW BE SUCCESSFULLY PRODUCED IN SPACE.

APPLIED PROJECTS SHOULD BEGIN NOW WHILE THE SCIENCE BASE IS BEING ESTABLISHED.

FIGURE 5

INDENTIFY POTENTIAL COMMERCIAL AREAS

FURNISHING OF EQUIPMENT AND SERVICES (COMMERCIALIZATION)

TOO EARLY TO IDENTIFY POTENTIAL OF OTHER AREAS

PROMISING AREAS

- BIOPROCESSING (MDAC)
- CONTAINERLESS PROCESSING (UNLIMITED)
- CRYSTAL GROWTH (LIMITED)
- RESEARCH (INDUSTRY SPONSORED)

FIGURE 6

TASK B: DATA ANALYSIS

The most significant data available from this effort came from the personal interviews with people who were knowledgeable of and interested in the MPS program. Other useful data came from NASA reports which document the previous and ongoing MPS-related research programs, describe the facilities available for MPS research, and discuss NASA programs designed to encourage commercialization of MPS. Published scientific reports from NASA-sponsored research provided useful information on the status of MPS technology.

The analysis was directed to determining what course of action should be pursued to encourage commercialization of MPS in the U.S.A. After each interview the investigators critically reviewed the discussion with the purpose of discovering barriers to commercialization, either perceived or real. The attitudes, aspirations, frustrations, previous successes, and hopes of the individuals interviewed assisted the investigators in developing a clear picture of the current status of the MPS program. The following sections of the report present the investigators' views on the program resulting from analyzing the data obtained from the interviews and documents.

Business Infrastructure Required to Achieve Commercial MPS

Successful commercialization of MPS will require a sophisticated infrastructure including at least the following:

- o A reliable space delivery vehicle and support system
- o A solid basic science research program
- o One or more space service companies that can provide facilities to companies who do not desire to develop their own hardware and manage the NASA interface problem
- o Companies interested in producing products in space
- o Financing arrangements that can adequately reward the high risk involved with MPS

The first element is in place. The NASA space shuttle program has demonstrated through several nearly flawless flights that a reliable vehicle with adequate technical support services is available. The principal drawbacks to the system are the high costs and long lead times associated with its use. This requires that the products produced have a high value per unit volume or be unique to space processing. In time, if private industry perceives that it can achieve comparable results at lower costs or more favorable flight schedules with other delivery systems, private rocket systems will be developed. Several such efforts are already underway. If these develop successfully, NASA can proceed with other projects of greater sophistication leaving "routine" MPS to private industry.

The science base element, while not complete, is progressing. NASA Science Working Groups are functioning in several distinct areas providing a forum for review and discussion of the science programs among capable scientists, many of whom have a long history with space science.

These groups meet periodically to assess the state of MPS science and to advise NASA on directions for future research. They play a strong role in advancing MPS science. Considerable effort has been expended in ground-based research, both at NASA facilities and at industrial and university laboratories, to develop an understanding of the influence of low gravity on physical phenomena. Actual flight experiments have been limited but plans for additional experiments are underway. The science program is fundamental to the entire commercialization process. Successful scientific low gravity experiments will be necessary to demonstrate not only scientific principles, but the viability of low gravity as a significant commercial process parameter.

Space service companies must be available to provide the facilities and interface with the space delivery system. Many companies having a desire to use materials which have been processed in space will desire to purchase services from others rather than develop their own capabilities. Several of the large areospace companies have both interest and capabilities in this area. They represent a significant resource to the commercial MPS program. At the same time it is likely that small innovative technical firms may also find it possible to develop capabilities in their specialties which they may profitably market.

The most vital element in the infrastructure consists of those companies who desire to produce products in space or from materials processed in space. The number of companies who are now convinced that MPS can play a significant role in their product line is indeed very small. To date only McDonnell Douglas appears to be convinced that materials can be commercially processed in space now. Most companies, with interest in MPS, are taking a passive role waiting for the technology to be further developed. It is this element of the infrastructure that needs significant cultivation. The NASA Industry Commercial Applications Working Group project which will be discussed later is addressed to this area.

Financing of MPS projects is not different from other high risk, long-term projects to which many companies are accustomed. A company must be convinced that the benefit/cost ratio for an MPS project is at least as high as desirable competing projects. Some companies may make moderate investments to provide a window on the technology or to enhance their high technology image with investors and customers, but large investments will have to be prioritized against competing projects within the company. Small companies, though lacking resources, probably have more flexibility in funding new projects. For example, R&D limited partnerships may prove to be viable vehicles for such companies since the investors lower their effective risk by achieving some tax writeoffs in the early stages of the project. For any size company the MPS investment business arrangements must meet the logical business criteria illustrated in Figure 7.

LOGICAL BUSINESS ARRANGEMENTS

CORPORATE INVESTMENTS MUST COMPETE WITH OTHER OPPORTUNITIES

RISKS UNRELATED TO THE MARKETPLACE MUST BE REDUCED TO A MINIMUM

ARRANGEMENTS MUST RECOGNIZE THE R&D CHARACTER OF MPS, UNCERTAINTY IN TIME AND ABILITY TO PERFORM

FIGURE 7

Incentives and Disincentives for MPS

The principal goals for MPS are:

- o Produce a desirable material or product in the space environment in a cost effective manner that either cannot be produced on earth, or has characteristics superior to materials or products produced on earth
- o Utilize the space environment to improve the understanding of physical phenomena associated with ground-based processes
- o Develop model materials which might serve as standards for earth-processed materials
- o Demonstrate the ability to carry out complex materials processing in space

Several incentives exist for achieving these goals, including:

- o National pride in maintaining America's leadership in space science
- o International prestige important to America's economic and political interaction with other countries

Private companies, while generally supportive of the first two incentives, are much more interested in financial incentives. It is apparent that most companies feel the state of knowledge and experience with MPS does not warrant significant investment of private money at the present time. Impediments which discourage commercial investment in MPS at this time include the following:

- o The state of knowledge about the low gravity environment and its effect on processing materials into useful products is weak
- o Experience of producing new materials or products in space is lacking
- o Proven experimental flight hardware is extremely limited
- o Flight experiments are both difficult and costly
- o Flight hardware is extremely expensive
- o Long lead times are required for experiments and scheduling lacks flexibility
- o The interface problem between the ground-based concept and the flight requires extensive effort by people familiar with NASA procedures
- o Service companies that can serve as the NASA interface link, provide and operate sophisticated materials processing facilities, and provide complete flight services are being planned but are not now operational

NASA/Industry Working Agreements

NASA has been extremely innovative in developing three agreements permitting interaction and cooperation between private companies and NASA. The Technical Exchange Agreement, Guest Investigator Agreement and Joint Endeavor Agreement permit private companies access to NASA facilities at three different levels of involvement. The agreements provide a formal mechanism for sharing NASA-developed technology and facilities with the private sector while avoiding charges of favoritism or unequal treatment to individual companies.

A number of companies have signed such agreements with NASA. Clearly the most successful arrangement to date is the McDonnell Douglas Joint Endeavor Agreement pertaining to electrophoresus techniques for separating pharmaceutical materials. This company has been sufficiently impressed with the commercial potential for separation of biologic compounds using an electrophoresus device in low gravity to make substantial financial commitments to this program. Corporate funds have been used to design and perfect an electrophoresus device that produced significant results on the STS-3 shuttle flight. The results from an experiment performed for NASA in accordance with the Joint Endeavor Agreement reported by McDonnell Douglas to the Bioprocessing Science Working Group meeting held October 24, 1982 in Washington, D.C. were well regarded by the scientists present. The company has combined its expertise in aerospace engineering with its biology team to develop a useful production apparatus. Furthermore, the company entered into an agreement with a large pharmaceutical company to package, distribute and market the materials produced. It now appears that this will be the first commercial success for the MPS program and it certainly justifies the Joint Endeavor concept.

However, for small companies the Joint Endeavor approach may not be viable, at least in the early stages of a project. The Joint Endeavor Agreement between NASA and GTI corporation is a case in point. GTI is headed by a technical entrepreneur with a proven track record. The company entered into the JEA with NASA and recruited several high quality people including a JPL manager with a proven record of achievement in directing interplanetary space probe projects, and a very capable senior marketing manager. GTI's objective was to be in the space services industry providing facilities for space processing on NASA shuttle flights for other companies. Its first project was to be a relatively simple furnace capable of heating samples to a given temperature, holding the temperature constant for a predetermined time and then allowing the specimen to cool. This would permit melting and solidification studies on small cylindrical samples of materials of interest to other companies. Preliminary estimates indicated that such a facility could operate on board the shuttle and be profitable for GTI. This facility would then be followed by more complex facilities such as furnaces suitable for crystal growth experiments.

Clearly the concept of a service company that can provide turnkey space services, including the interface with NASA, is needed if MPS is to become commercially viable on a widespread basis. Thus, the basic business philosophy of GTI was valid. However, as the first project proceeded it became apparent that the company's preliminary market projections could not be obtained. After considerable expenditure of funds by GTI the JEA Agreement was terminated and the project disbanded.

In retrospect it appears that a different course of action than the JEA Agreement may have been more beneficial to NASA and GTI in the early stages of this project. For example, if NASA could have funded the design and fabrication of the furnace and then contracted with GTI to manage the marketing and customer interaction, the program would probably have been successful. The customers could have obtained the service at a much lower price and a number of private companies would have become involved in the MPS program. While the initial cost to NASA would have been higher, the program would have been established on a much sounder basis and proceeding with much greater industrial involvement. Instead GTI and NASA have terminated the agreement with disappointment on both sides. Failure of a well-managed small company committed to commercialization of MPS to be successful with the JEA raises doubts about this mechanism for dealing with small companies in the early stage. If NASA could have provided additional financial assistance such as supplying the furnace for the project, thus enabling the company to become established, and then executed the JEA, the project would have had a higher probability of success.

TASK C: BUSINESS RELATIONSHIPS

Existing Corporate Programs

Among the large companies visited only McDonnell Douglas was investing significant corporate funds in product-related MPS technology. Rockwell International has an active program underway to sell space services to capitalize on their experience as the major space shuttle contractor. Ball Brothers is developing sophisticated flight hardware for use in MPS technology and is also interested in providing space services. NASA can provide encouragement to these efforts by being supportive and, where appropriate, providing contract research and development funds. Due to the special expertise these companies have in aerospace technology they are also logical candidates as joint venture partners for process-related companies.

Two small companies have launched specific MPS projects in recent years. The experience of GTI has already been mentioned. Unfortunately GTI has recently terminated their MPS activities. More recently Materials Research Associates has signed a Joint Endeavor Agreement with NASA to produce galium arsenide crystals in space. The company appears to combine the talents of a dedicated entrepreneur, an established scientist with extensive experience in crystal research related to MPS, and adequate financial backing. This is an exciting concept, and if successful, will be a significant achievement for commercialization of MPS to produce a valuable material. Extensive effort will be required to demonstrate its success. Funding academic research related to the aims of the company is one effective method NASA can use to support this company.

Figures 8a and 8b summarize the investigators' views of several company efforts.

VIEWS ON COMMERCIAL ENDEAVORS

MDAC

- GOOD SCIENCE COMBINED WITH OUTSTANDING SPACE TECHNOLOGY
- LOGICAL COMBINATION OF AEROSPACE AND PHARMACEUTICAL FIRMS
- COMPANY EXCITED ABOUT COMMERCIAL PROSPECTS

MRA

- INTERESTING COMBINATION OF ENTHUSIASTIC ENTREPRENEUR, ADEQUATE FINANCING AND RESPECTED SCIENTIST
- STRONG FOCUS ON HIGHVALUE PRODUCT
- TEAM STILL IN FORMATION STAGE

FIGURE 8a

GTI

- EXCELLENT TEAM: ENTREPRENEUR, PROJECT ENGINEER, MARKETING MANAGER
- BOLD UNDERTAKING
- FURNACE COSTS MAY BE TOO HIGH TO MAKE PROJECT VIABLE
- MARKET UNCERTAIN
- COMPANY HAS INTEREST IN SUPPLYING BROAD RANGE OF SERVICES
- SUCCESS IS VITAL IF SMALL COMPANIES ARE TO PLAY A SIGNIFICANT ROLE IN MPS

BALL BROTHERS

- EXPERIENCED, CAPABLE AEROSPACE COMPANY
- EXCELLENT, EXPERIENCED TEAM
- LOGICAL BUSINESS CONCEPT
- COMPANY WILL HAVE NASA AS A MAJOR CUSTOMER

FIGURE 8b

Mechanisms for Encouraging MPS

o Contract Research

A long standing and extremely effective method of encouraging industry involvement in technology developed by government agencies in the use of contract research funds. This technique has been used extensively by NASA for many years. It was through NASA contract research funds that McDonnell Douglas developed much of the aerospace expertise in biology and sophisticated engineering design that enabled the company to utilize electrophoresus technology in space. This, of course, lead to a Joint Endeavor Agreement and eventually to successful experiments on board the shuttle.

The Atomic Energy Commission used contract research funds very effectively in the 1950's to encourage U.S. industrial firms to enter the field of nuclear power. By receiving contract research funds on projects of interest to the government, a number of companies developed expertise in the nuclear energy field at low risk. This mechanism continued for several years until some of the companies were able to justify completely private investments in nuclear power. America would not have developed commercial nuclear power plants over a relatively short time frame without government support to private industry. Without arguing for or against nuclear energy, the point is made that contract research funds were very useful in meeting what was at the time a clear government objective.

A similar approach might be considered by NASA on a much smaller scale to encourage commercialization of MPS. Contract research can be used effectively with any size company provided the company has the necessary technical capacity to make substantial contributions to MPS technology. Where appropriate cost sharing could be used to insure genuine interest by the contractor.

Figure 9 outlines one example arrangement in which NASA and a private company could jointly participate in a contract research program which might lead, through the steps indicated, into a successful MPS commercial endeavor.

o Small Business Innovation Research Grants

Recognizing the effectiveness of small high technology firms in developing innovative technical products and processes in the United States over the last two decades, Congress created the Small Business Innovation Research Program in July 1982. The Act requires ten Federal agencies including NASA to allocate 0.2 percent of their contract research budget to small firms. The legislation was based on a program created by the National Science Foundation and tested over a three-year period. Phase I grants of $30,000 were provided to the successful small technical companies which responded to NSF solicitations for proposals in specified areas. These companies were eligible to apply for Phase II awards of amounts up to $200,000. The success of the program encouraged Congress to legislate the expanded program. Under the new SBIR program most of the Phase I awards will be for $50,000 and the Phase II awards will be for $500,000. It is anticipated that a small company can make sufficient progress on its project during the Phase II award to attract additional development funds from private sources in larger amounts to commercialize the product or process.

POSSIBLE BUSINESS ARRANGEMENTS

NASA FUNDS COMPANY RESEARCH

COMPANY CONTRIBUTES A RANGE OF RESOURCES

- FACILITIES
- FINANCES
- PERSONNEL
- FEE

NASA GUARANTEES A MARKET FOR PRODUCT

- LEASEBACK
- PURCHASE OF PRODUCT (RESEARCH, SAMPLES, DATA)

DATA RIGHTS NEGOTIATED DEPENDING UPON CONTRIBUTION

- BACKGROUND RIGHTS
- EXCLUSIVE LICENSE TO GOVERNMENT OR COMPANY
- ROYALTY FREE LICENSE

COMPANY CREATE A NON-PROFIT ENTITY TO WHICH NASA COULD GIVE GRANTS

NASA AND COMPANY SET UP A JOINT VENTURE

NASA CREATE A GOVERNMENT CORPORATION (SYNFUELS)

FIGURE 9

The SBIR program has interesting possibilities for small technical firms interested in MPS. Phase I funding would permit small companies to investigate MPS projects with commercial potential. Those companies developing interesting concepts could be awarded Phase II funding. Once a project is sufficiently developed it may be possible to attract additional private funding from venture capital sources, joint ventures with larger companies, R&D partnerships, or from public stock sale.

There is certainly no guarantee that the SBIR funding will lead to successful commercial MPS projects, but NASA is obligated to participate in the SBIR program, and MPS is an area that holds great promise for small firms. This is particularly true if means can be found to combine the innovative talents of small companies with the resources of large corporations. Small companies with commercially interesting, proprietory, technology are often of great interest to large corporations as partners in joint ventures or as candidates for acquisition. The SBIR program could serve as an interesting vehicle to combine the innovative talents of small technical companies with the vast resources of large corporations. It should be considered as an additional mechanism to the TEA, GIA, and JEA for furthering the commercialization of MPS.

o Use of NASA/Industry Agreements

One obvious potential method for a company to interact with NASA in the MPS program is to utilize the formal arrangements NASA has established. The Technical Exchange Agreement represents a relatively easy way to establish working relationships with NASA which could be extended to Guest Investigator and Joint Endeavor Agreements at an appropriate time. The McDonnell Douglas experience to date is an excellent example of the validity of the Joint Endeavor Agreement. NASA has benefited from the experimental results and McDonnell Douglas has enjoyed the benefits of the space shuttle at relatively low cost.

In the future it is likely that use of the working agreements will become more common, but at present the agreements have not been used extensively by U.S. industry, even though they have been given significant publicity. It appears that most U.S. companies will require either greater evidence the program will provide reasonably near term financial payoff or economic subsidies to encourage their participation in the program.

o Joint Venture Arrangements with Small and Large Firms

Small technology firms often succeed by being very innovative and moving rapidly into areas where opportunities exist. This capability is one ingredient necessary to succeed in commercial MPS. Large companies while often unable to achieve the same level of innovation as small companies, are generally much stronger in manufacturing, marketing and distribution, also important ingredients for commercially successful MPS. In addition the financial resources of large companies are much greater. One means of combining the innovative talents of small companies with the extensive resources of large companies in the formation of a joint venture.

Joint ventures between large and small companies may prove useful in encouraging commercial MPS. The small company may initiate the project and develop it far enough to demonstrate technical feasibility, using contract research funds, R&D partnerships funds, or direct investment capital. At this point the small company may logically seek a large corporate partner with market interests related to the project. By forming a joint venture where the small company contributes the technology and the large company provides capital and market outlets, both firms could benefit. Joint ventures are fairly common in the United States, and a wide variety of contractual arrangements exist to protect the partners and provide appropriate rewards.

This mechanism holds considerable promise for commercialization of MPS providing small companies can be encouraged to develop the necessary technology.

o Commercial Spinoffs from NASA Science Programs

In the past 20 years in the United States an extremely effective mechanism for achieving commercial success in high technology endeavors has been the spinoff of small companies from academic institutions or larger organizations. This usually occurs when a capable, well-informed technical entrepreneur senses that a commercial opportunity exists which he feels can be exploited. With sufficient encouragement he may be inclined to leave his existing position and start his own company. This mechanism has been particularly prevalent and successful in such industries as computers, computer-related products, biotechnology, and biomedical devices.

The study examined the potential for establishing business relationships for pursuing MPS activities utilizing the talents and knowledge of NASA-funded researchers who have been actively engaged in MPS-related research. It was anticipated that there may be some individuals associated with MPS research, particularly the NASA-funded P.I.'s, with sufficiently interesting ideas to form the basis for a company which could attract outside investors. During the interviews a special effort was made to seek out those individuals. While several individuals indicated an interest in becoming involved with private companies, either as active consultants or owner-managers, only one was actively engaged in a serious effort to start a new private company. This company will concentrate initially on providing space services to other organizations including sophisticated furnaces for crystal growth. Another group of researchers has an interesting product that can be manufactured in space, but it is not clear that the market for the product is adequate to justify the equipment development costs.

The investigators were convinced that the P.I.'s have little incentive to risk undertaking new private MPS business ventures. In most instances the technology is not sufficiently advanced to warrant the risk of losing research support or academic standing. As future developments delineate clear cut space opportunities it is likely that some people closely related to the technology will become interested in starting their own companies. Under proper circumstances this action should be encouraged.

o NASA/Industry Commercial Applications Working Groups

As this study proceeded, it became apparent that NASA had established good rapport with the science community and that scientists from universities and government were participating effectively in a number of specific science working groups to evaluate the results of NASA-sponsored research. This appears to be an excellent method to keep the science community informed and to obtain useful input and guidance to the NASA science program.

It also became apparent that a significant industrial viewpoint concerned with commercialization of the scientific findings was lacking. It is not enough to fill the technical literature with results of scientific investigations and wait for industry to evaluate the results and commercialize them. American industry should be brought into the picture early to permit industrial assessment of the results of the research and to position companies to effectively utilize the results of the research in commercial endeavors. NASA has made an effort to get industry involved in MPS with limited success.

An additional approach to encouraging industry involvement would be the formation of several NASA/Industry Commercial Application Working Groups. The groups would be formed around specific process technologies and would include representatives from appropriate U.S. companies with the capabilities and interests to provide significant input into the program, members of the financial community, invited members from the appropriate NASA science working group and NASA personnel. Two-day meetings would be held annually, or more often if appropriate, to inform the industry people of the status of NASA research, to more fully utilize NASA facilities and programs, to seek industry input on future research directions, and most importantly, encourage industry to proceed with commercialization as opportunities develop.

This concept will likely take several years to produce significant industry investment. However, it is inexpensive and it will create a cooperative partnership atmosphere that will be beneficial to the entire program. Figure 10 summarizes the goal and objectives of the NASA/Industry Commercial Applications Group concept.

Funds have been provided for a trial project to determine the feasibility of this approach. Results of the first meeting of a group focusing on containerless processing with emphasis on glasses and glassy materials were encouraging. Figure 11 illustrates a potential interaction scenario for a company that begins its involvement by affiliation with a Commercial Applications Group.

NASA/INDUSTRY COMMERCIAL APPLICATIONS WORKING GROUPS

GOAL

HAVE THE SAME CAREFUL AND PROFESSIONAL ATTENTION PAID TO THE COMMERCIAL ASPECTS OF THE RESEARCH PROGRAM AS IS NOW PAID TO THE SCIENTIFIC ASPECTS

OBJECTIVES

PROMOTE, ENCOURAGE AND OBTAIN INDUSTRY INVOLVEMENT IN RESEARCH PROGRAM

PROVIDE ON-GOING MECHANISM FOR INTERACTION BETWEEN SCIENTIST, INDUSTRIALIST AND FINANCIER

PROVIDE MECHANISM FOR INSURING COMMERCIALIZATION ASPECTS OF MPS ARE CONSIDERED IN THE ON-GOING PROGRAM

PROVIDE A COMMERCIAL POTENTIAL REVIEW TO SCIENCE AND INDUSTRY RESEARCH PROPOSALS

FIGURE 10

INTERACTION SCENARIOS

MUST PROMOTE INDUSTRY INVOLVEMENT IN RESEARCH LEADING TO INVESTMENT

INVITE PARTICIPATION IN COMMERCIAL APPLICATIONS WORKING GROUPS

FUND COMPANY RESEARCH OF INTEREST TO NASA AND COMPANY BUT NOT NECESSARILY OF INTEREST TO PEER GROUP

- BUILDS COMPANY CAPABILITY
- EXCITES INTEREST IN PROGRAM
- FUNDS EDUCATION OF COMPANY
- BUILDS RELATIONSHIPS
- COMPANY MUST JUSTIFY NOT ONLY ON TECHNICAL MERIT BUT ON COMMERCIAL POTENTIAL

FUND COMMERCIALIZATION DEFINITION STUDIES FOR COMPANY

COMPANY ENTERS PRESENT PROGRAM

- GIA
- TEA
- JEA

FIGURE 11

Conclusions

The principal conclusion from this study is that the current state of knowledge relating to processing materials in space is insufficient to warrant investment of private funds. With the exception of McDonnell Douglas and several firms developing businesses to supply space services, U.S. corporations are unwilling to commit significant funding to MPS. Furthermore, most of the NASA science community agrees that large scale private investment is not appropriate at present.

Recommendations

Efforts to involve U.S. corporations in commercial MPS programs should continue. It is recommended that NASA continue to publicize results and to seek mechanisms that will encourage private involvement. Utilization of contract funds to encourage private company involvement and eventual private investment in MPS is recommended. Contract funds must be used carefully on targeted objectives, with cost sharing by the contractor where appropriate to encourage serious interest in MPS by corporate management. Efforts to encourage cooperative arrangements between large and small companies should be encouraged. It is further recommended that NASA continue its experiment with NASA/Industry Commercial Applications Working Groups to determine if this is a viable mechanism for encouraging commercialization of MPS.

Appendix I Individuals Interviewed

NASA Headquarters - Washington, D.C.

Dr. Louis Testardi
Mr. Charles Yost
Dr. William Oran

NASA MSFC - Huntsville, Alabama

Mr. Richard Brown
Dr. Robert Nauman
Mr. Lowell Zoller
Mr. William Vardaman
Dr. Roger Kroes
Mr. Harold Alkins
Mr. Walter Wood
Dr. Robert Snyder
Dr. Alex Lehozky
Dr. E. Etheridge

NASA MPL - Pasadena, California

Dr. Taylor Wang
Dr. Martin Barmatz
Dr. Alan Rembraum
Dr. Dan Kerrisk
Dr. Dan Sniederman

MdDonnell Douglas - St. Louis, Missouri

Mr. John Yardley (Interviewed in Bethesda, Maryland)
Mr. James Rose

Thiokol Chemical Company - Brigham City, Utah

Mr. Gilbert Moore

Lawrence Livermore Laboratories - Livermore, California

Dr. Charles Hendricks

EG & G - Goleta, California

Mr. William F. Schnepple

GTI - San Diego, California

Mr. James LeFleur
Mr. Esker K. Davis
Mr. David Keaton

Polysciences, Inc. - Warrington, Pennsylvania

Dr. B. David Halpern

Battelle - Columbus, Ohio

Dr. Kenneth Hughes
Ms. Beam
Mr. Debiskdor

Rockwell International - Downey, California

Mr. Edward Ash
Ms. Nancy Williamson
Mr. James M. Mansfield
Dr. Y. S. Kim
Mr. Michael J. Martin

Rockwell International - Science Center - Thousand Oaks, California

Dr. Derek T. Cheung
Dr. M. David Lind

General Electric Company - Valley Forge, Pennsylvania

Dr. Thomas Frost
Mr. Hugh Alvarado
Mr. Frank Viciente

Ball Brothers Inc. - Denver, Colorado

Mr. Ronald Greenwood (Interviewed in Seattle, Washington)

Pennsylvania State University

Dr. Guy Rindone
Dr. Paul Todd

Clarkston College

Dr. William Wilcox
Dr. R. S. Sugramanian

Lehigh University

Dr. John Vanderhoff
Dr. Mahamed El-Aasser
Dr. J. F. Micale

University of Arizona - Tucson, Arizona

Dr. Malin Bier
Dr. Richard Mosher

Massachusetts Institute of Technology - Cambridge, Massachusetts

Dr. Merton Flemming
Dr. Harry Gatos
Dr. Gus Witt
Dr. David Roylance
Mr. Joe Vitale

University of Utah

Dr. Franz Rosenberger
Dr. James Brophy

University of Missouri - Rolla, Missouri

Dr. Delbert Day

Rennselear Polytechnic Institute - Troy, New York

Dr. Robert Doremus
Dr. Martin Glicksman
Dr. H. Wiedemeyer

Iowa State University

Dr. Verhoven

Seattle Pacific University - Seattle, Washington

Dr. Herbert Kierulf

University of Oregon Medical Center

Dr. Geoffery Seaman

Consultants

Dr. Ted Kern, San Diego, California
Dr. Norbert Kriedl, Santa Fe, New Mexico